

Long Term Monitoring of the Io Plasma Torus during the Galileo Encounter Final Report

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Introduction

In the fall of 1999, the Galileo spacecraft made four passes into the Io plasma torus, obtaining the best in situ measurements ever of the particle and field environment in this densest region of the Jovian magnetosphere. Supporting observations from the ground are vital for understanding the global and temporal context of the in situ observations. We conducted a 3 month-long Io plasma torus monitoring campaign centered on the time of the Galileo plasma torus passes to support this aspect of the Galileo mission. The almost-daily plasma density and temperature measurements obtained from our campaign allow the much more sparse but also much more detailed Galileo data to be used to address the issues of the structure of the Io plasma torus, the stability mechanism of the Jovian magnetosphere, the transport of material from the source region near Io, and the nature and source of persistent longitudinal variations. Combining the groundbased monitoring data with the detailed in situ data offers the only possibility for answering some of the most fundamental questions about the nature of the Io plasma torus.

Observations

Observations were performed over 42 nights between 10 September and 8 December 1999 with the Lick Observatory 0.6-m coudé auxiliary telescope coupled to the Hamilton echelle spectrometer. The observational techniques were identical to Brown (1995): throughout an observing night alternating observations were made through a narrow-band 6725Å filter, which isolates emission from S^+ , a tracer of the plasma torus, and a narrow-band 5890Å filter, which isolates emission from neutral Na, a tracer of the extended neutral atmosphere of Io. During each 40-minute integration, the observing slit was centered on Jupiter and placed parallel to the torus centrifugal equator (for the S^+ observations) or parallel to Io's orbital plane (for the Na observations). Each integration gives a measurement of line-of-sight emission intensity, velocity, and velocity dispersion (temperature) as a function of radial distance.

Results

The Io plasma torus underwent large scale brightening and then fading during the Galileo encounters. Figure 1 shows the relative intensity at 5.8 R_J (Jovian radii) on the dawn side of Jupiter as a function of time from 10 September until 8 December. The factor of 3 brightness increase roughly corresponds to a 70% torus over this time period. Similar brightness increases in the past have been attributed to volcanic variability on Io (Brown and Bouchez 1998). The sodium emission intensity, however, does not follow the same pattern observed from a volcanic outburst in 1992. The emission is relatively constant until the end of the observing period, when it jumps by a factor of ~ 2 . As has been observed for all other long term measurements of the Io plasma torus intensity, the emission is highest around torus longitudes of ~ 160 degrees and lowest at approximately 0 degrees System III longitude (Fig 2). The magnitude of variation is similar to that seen in earlier observations.

While some of the plasma torus periodicity is reproducible and stable, much is not. In particular, a pseudo-periodic density variation at a period slightly longer than the System III rotation period of Jupiter has also been consistently observed. This variation has been called System IV. The period is not known well enough to predict that phase at most times, and the phase of the periodicity has also been seen to suddenly shift over time scales of months. Thus one of the key goals of this project was to define the System IV phase for the times of the Galileo encounters to allow the different periodic variations to be sorted out.

First, we determine if the System IV variation still persists in 1999. We construct a Lomb-Scargle periodogram in an attempt to find periodic variation in the plasma torus. As usual, the two highest peaks correspond to the expected System III (9.925 hours) and System IV (10.214 hours) periods (Fig. 3). The System IV period appears to have shifted slightly to 10.234 ± 0.014 hours, marginally different than the canonical value. A phased plot at the System IV period (Fig. 4) shows the System IV variation and the phase during this time period:

$$\lambda_{IV} = ((JD - 2451000)/0.4264 \times 360 - 10) \text{ modulo } 360 \text{ degrees,}$$

where JD is the Julian date. System IV is defined such that the intensity peak occurs at 180 degrees on the central meridian. The above formula can be used throughout the Fall of 1999 to determine where System IV density peaks should be occurring in both Galileo and other ground-based data.

Case Study: The 11 October I24 Encounter

On 11 October 1999, Galileo made a pass through the densest region of the Io plasma torus from a longitude of 265 to 45 degrees. Based on known System III variations, the spacecraft should have passed through the hottest and least dense part of torus equator at approximately 0 degrees longitude. On the date of the encounter, our observations show that System III and System IV were almost precisely aligned, meaning that the known equatorial density variations were amplified by the System IV variation. Figure 5 shows the two week period around the I24 encounter. The magnitude of the variability of the torus is stronger than usual owing to the System III and System IV alignment. Detailed analysis of these types of variations, coupled with analysis of the variability seen by the Galileo probe, will allow the disentanglement of the various spatial, periodic, and stochastic variations in the Io plasma torus. Only with such an understanding will the Galileo data achieve its full value.

Future Work

This project has successfully provided critical support to the Galileo mission for understanding the *in situ* measurements of the Io plasma torus. Unfortunately, funding for the project was provided only for one year at a reduced rate, so while the data have been obtained and reduced, no additional funding exists for detailed analysis and publication. The data have been presented to the Galileo community at an Io workshop (Boulder, Feb 2000) and at the Jupiter meeting (Boulder, June 2001) and interested scientists have received the data for their own intercomparisons.

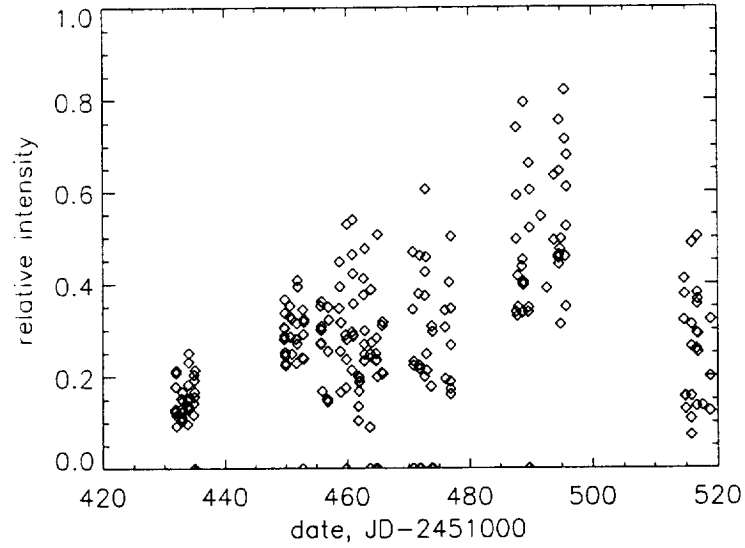


Figure 1. Intensity of emission from the 6731Å S⁺ line of the Io plasma torus over a 4 month period. Much of the apparent scatter in the observations is due to 2 overlapping periodic brightness modulations.

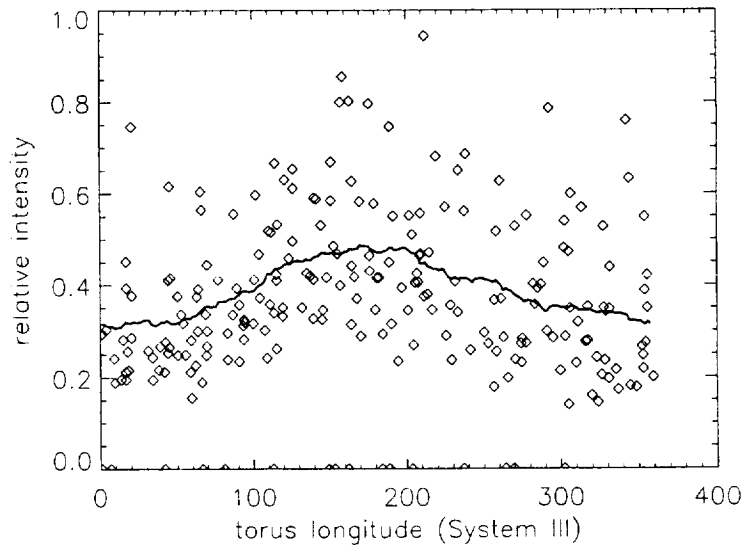


Figure 2. Intensity of emission from the 6731Å S⁺ line of the Io plasma torus over a 4 month period as a function of System III longitude at the ansa.

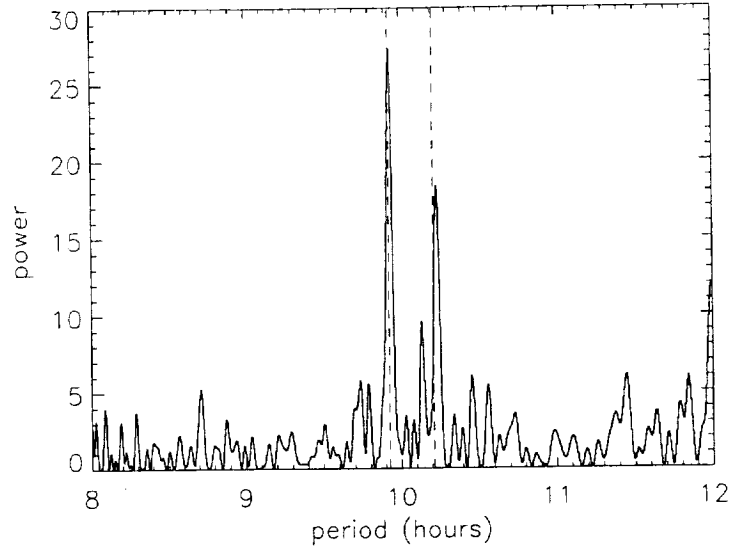


Figure 3. Lomb-Scargle periodogram of the intensity of the Io plasma torus over the 4 month observing period. The two significant periodicities seen are at the System III period of 9.925 hours and at the previously observed System IV period of 10.214 hours.

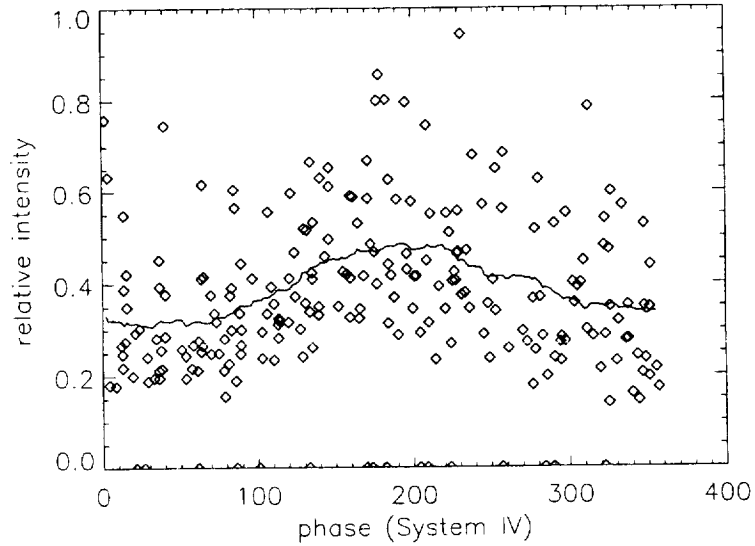


Figure 4. Intensity of emission from the 6731Å S⁺ line of the Io plasma torus as a function of System IV longitude. Note that the phase of System IV appears not to be stable on time scales of months to years. The phase is thus defined at each epoch as having the intensity peak at 180 degrees.

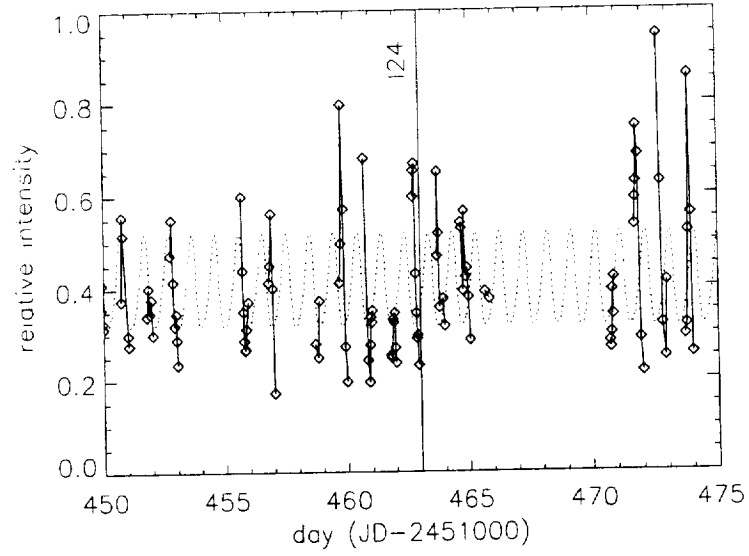


Figure 5. Intensity of emission from the 6731\AA S^+ line of the Io plasma torus for a 2 week period surrounding the I24 encounter. The dotted line shows the expected periodic behavior from the known System III variation. A much higher magnitude of variability occurs around the time of the encounter owing to the alignment of the System III and IV periodicities.